THE BUFFALO RIVER: AN INTERESTING MEANDERING STREAM.

BY

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The Buffalo River is a swift trout brook rising in Buffalo Lake about twelve miles north of Detroit, Minnesota, and flowing southwest to Muskoda on the shore-line of the ancient Lake Agassiz, where it turns in a northwesterly direction across the old lake bottom till it joins the Red River of the North near Georgetown.

By the direction of its flow, its velocity, and the behaviour of the river itself, it is divided into halves, quite distinct from each other. The upper portion flows off from the "Height of Land" down to the level "Red River Valley," and has a steep gradient, amounting, in the twelve miles between Hawley and Stockwood, to 200 feet, while the lower slope is only about one fourth as steep. Consequently, the upper portion is much swifter than the lower, and babbles along over the rocks in its bottom with a noise which can be heard for a quarter of a mile. The upper river cuts banks of sandy drift from which clay is almost absent. Its course is full of sandbars and obstructed by many boulders, but its water is usually clear and sparkling. Contrasting with this is the sticky gumbo clay of the Red River Valley through which the lower reaches flow. This is only with difficulty taken up by running water, and is then in a finely-divided state, giving the water the turbid appearance characteristic of the streams of the region. This gumbo, once in suspension, settles out but very slowly, so that there are no deposits in bars and the like along its bed, but its channel is swept deep and clean like a canal.

The upper portion furnishes the most remarkable example of a meandering stream the writer has ever been fortunate enough to observe. The swift water working on the soft gravel has a cutting power (or, better, *carrying power,* for there is no cutting to be done) which is almost unbelievable. Everywhere the channel is shifting with extraordinary rapidity as the stream meanders about on its flood-plain. The plate shows a set of meanders near Muskoda which show very well the general character of the upper portion of the river. To the left is a meander in process of being cut off, while in the centre are shown remnants of three former meanders long since cut off and now nearly filled up. A set more striking in its contor-

tions and in the number of cut-offs in process of formation, but sufficiently obscured by brush to render photography impracticable, is shown in Fig. 1, which was sketched from a high hill overlooking the stream about five miles farther up-stream than the plate.

To this habit of rapidly meandering from side to side in its flood-plain the lower river offers a strong contrast. Like all streams of the Red River Valley, it is extremely crooked; but its crooks are relatively stationary, not rapidly shifting. Though bends often approach quite close to each other, cut-offs are of rare occurrence. Frequently the river is actively cutting on both sides of its bed, and deposition, such as is a necessary part of meandering in filling up the cut-offs, is entirely insignificant. There is no flood-plain, but the crooks are deeply sunken into the plain over which the river flows. They belong, therefore, to the class of entrenched meanders.

It seems desirable at this point to call attention to some looseness in the application of the

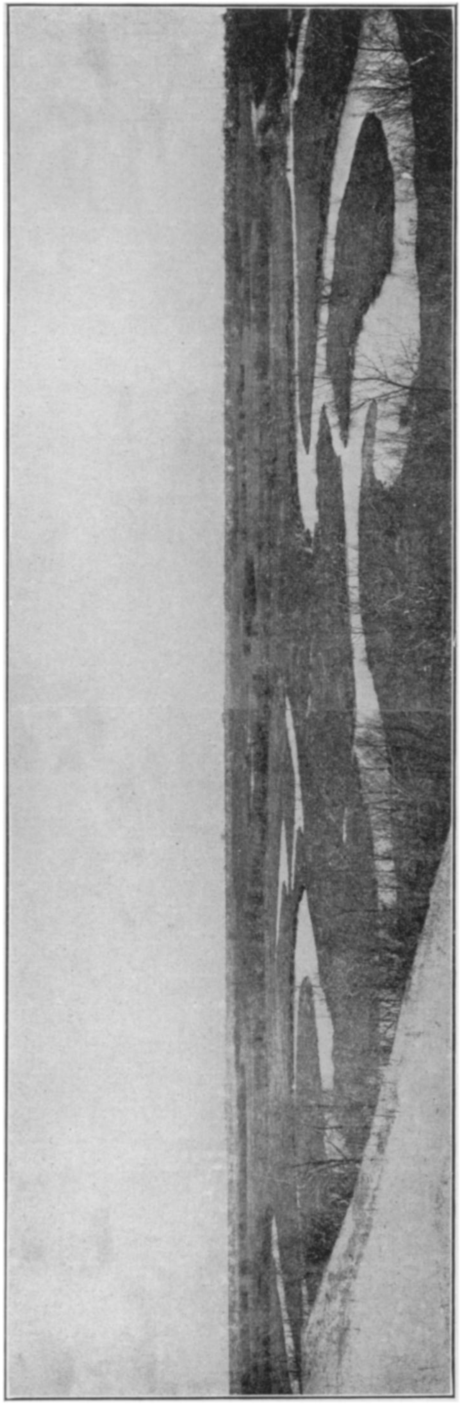

PLATE 1.—MEANDERS IN BUFFALO RIVER AT MUSKODA, MINNESOTA.

term *meandering.* Frequently by a meandering stream is meant simply an unusually crooked one, but if we recognize meander as the *process* which is described in the text-books under that name, we must limit the term to streams in which the process is going on. In other words, a meandering stream is not simply a stream which happens for any reason to be crooked, but one which is *actively* meandering—*i. e.*, alternately cutting and building out its banks so as to become progressively more and more crooked till it finally breaks across the bends and straightens itself for the time being.

In being at the same time a swift stream and one meandering rapidly the Buffalo is an exception not only to the ordinary phenomena of stream action, but also to the statements of the laws which have hitherto been enunciated as controlling the formation of meanders. For it is commonly believed and frequently asserted that

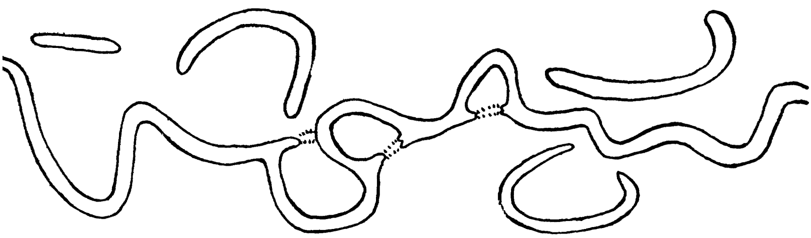

FIGURE 1.

meandering is possible only in sluggish streams. Russell* says, "Swift streams are not so easily turned aside as those which flow less impetuously. Hence the former maintain straighter courses than the latter." In the most recent work upon the subject—Chamberlin and Salisbury's Geology†—the same law is stated as follows: "A stream with an alluvial plain is likely to meander widely. In general terms this may be said to be the result of low velocity, which allows it to be easily turned aside." And a few sentences further on: "Even small creeks at high altitudes may meander if so situated as to have slight velocity. Trout Creek in Yellowstone Park is an example." The fact that such has been the statement of the law, and that it has met with wide acceptance, is sufficient evidence that it holds good in the great majority of cases. But, compared with other rivers, the Buffalo can hardly be said to have a low velocity, so that its crookedness must be accounted for in some other way. Since the laws of nature do not admit of exceptions, the statement of the

* Rivers of North America, p. 35, 1898. It should be noted in this connection that Mr. Russell's terms are not absolute but relative, and it is not impossible that his idea of a swift stream and the writer's differ widely.

† Vol. 1: 180–182. 1904.

law of meandering must evidently be at fault and require revision in order that it may cover both the ordinary slow meandering river and such as the Buffalo.

Let us look at the law *à priori* and examine it somewhat. Meanders are usually explained as follows: A stream is never exactly straight, and, if it were, some irregularity in the weathering of the banks or the side swing given by the entrance of a tributary would soon disturb its course and make it vary a little from a straight line. But at the same time the momentum of running water is very great, so that it resists vigorously any obstruction tending to deflect its course; and if forced to turn a corner, loses a considerable part of its power, which, of course, is expended in friction against the obstruction—in the case of a river, the outside bank of the bend. Thus it is that the outsides of the bends are cut away, and, as time goes on, the bend grows more and more crooked. This effect is further increased by the rebound of the current, which throws the water against the opposite bank, which in turn is cut away, so that all the little irregularities in the course of the stream tend to be accentuated and increase. Thus we see—paradoxically, indeed—that the very fact that water tends to flow in a straight line leads to its working out for itself a crooked channel. It is not easy to see how this general reaction of water could be affected by the velocity of the current, and it would seem difficult to fix a limiting velocity beyond which the tendency to meander would vanish in the case of a stream of a given size. On the contrary, it would appear from *à priori* grounds that the higher the velocity, the greater the force working on the outsides of the bends, and, consequently, the greater the rapidity in the formation of meanders. Thus we seem to be led to a conclusion exactly the reverse of that stated by the authorities cited—namely, that in the lateral wandering of a stream, as in most other lines of activity, other things being equal, the power is a function of the velocity, and that with every increase in the velocity comes a corresponding increase in the effect of the force acting.

That this conclusion has some justification in fact may be seen from the Buffalo River; for it is in the swift upper portion that the forces which cause meandering are most active and meanders best developed. In the lower portion, though the velocity is lower, lateral wandering goes on only very slowly, even where the stream is not sunk below the level of the country. This eliminates low velocity from consideration as one of the causes of meandering; for were it a conditioning factor in the process, we should certainly see some relation between the speed—or, rather, the sluggishness—of the

stream and its meandering. This is nowhere evident; and we shall have to pass on to the consideration of other possible causes.

But even though this is true, it is beyond question that the authorities quoted are correct in their statement of facts as far as most streams are concerned. Most commonly it is only sluggish streams that meander. If, then, there be no reason theoretically to prevent them, why is it so seldom that swift streams meander? A clue to this question may perhaps be obtained by a comparison of some other features of the streams in question. If we compare the valley of the Buffalo with those generally occupied by meandering streams on the one hand and with those of ordinary swift streams on the other we shall see some points of similarity and of difference which may be very instructive.

Most swift streams are young and flow in narrow cañons, while meandering streams occupy open valleys with broad flood-plains. The cañon is usually cut in hard rock very resistent to erosion as compared with the soft alluvium of the flood-plain. This difference suggests that the tendency to meander may be overcome by the hardness of the banks. But a meandering river is frequently seen slowly widening its flood-plain by cutting away the rocky bluffs at the sides, so that we must at once admit that a stream can cut in a lateral direction even into hard rock. Still, it is evident that in a cañon such cutting is neutralised by the much more rapid downward cutting, while in the broad alluvial valley downward cutting is almost at a standstill. Where a stream is rapidly digging downward and is entrenched in a cañon, it must remove a relatively enormous amount of material for every foot of side swing as compared with a river on a flood-plain. This makes lateral cutting very slow. Further, if it works downward very rapidly, it cannot develop any flood-plain, and so is prevented from suddenly shifting its course—an essential characteristic of meandering streams. This would suggest that meandering is in some way dependent upon the ratio of the downward to the lateral cutting power of a stream, and that it is because the downward cutting in most swift streams is very rapid as compared with the sidewise that meandering is rendered impossible. Upon what, then, does this ratio depend?

Perhaps one of the most conspicuous differences between a river in a cañon rapidly cutting downward and one meandering on a flood-plain is the relative load carried. The ratio of suspended matter to the power of transportation is much smaller in the swift stream, even though the absolute mass be much greater, because of the well-known law that the transporting power of running water increases

as the sixth power of the velocity. The scarcity of sandbars and alluvial deposits in cañons, even though the velocity is subject to enormous variations, while with every slight check the meandering river builds up a bar, is a sufficient demonstration of this fact. This difference arises partly because the transporting power of a swift stream is so enormous that it is well nigh impossible in the course of nature for it to receive enough waste to keep it busy, and *partly* because of the differences commonly present in the beds of the two classes of streams, swift torrents working over hard resistent rock, and sluggish rivers washing soft alluvium which crumbles as soon as wet. The work of a stream, whether it consists of moving solid particles of débris along its course or in wearing away the bottom of its bed and cutting downward, requires the expenditure of energy. Now, all the energy of a river is derived from the force of gravity acting on the water flowing down an inclined plane. This energy has a perfectly definite value for any slope, and can be used only once. It would, therefore, seem apparent that if a stream used up all its energy for the transportation of material supplied to it, it has no force left with which to abrade its bed. Consequently, a stream's power of deepening its channel depends on the ratio of load carried to its transporting power.*

While the load remains relatively small, channel-deepening goes on actively; but as soon as the stream becomes overloaded from any cause, it immediately stops cutting its bottom and begins to build it up, as, for example, in an alluvial fan, of which the various types of filled valleys are modifications, due to local conditions. When overloading is carried to an extreme possible only with a granular load like sand, which is not readily compacted and, after deposition, is full of interstices to hold the water, almost the entire force of the current may be expended in the effort to keep its load moving, and the river may almost disappear from view, seeping slowly through its shifting sands. A well-known example is the Platte River, whose channel is so choked with sand that it is barely able to maintain its flow at all. As meandering is impossible where downward cutting is very rapid, so also is it impossible in an overloaded stream like the Platte, since it has no energy left with which to attack even the softest bank. It would seem, then, that meandering belongs to a middle stage, where the load is so adjusted that the river is alternately cutting and filling up its valley.

In a process with so many complicating factors as river action,

* It must be remembered, of course, that a stream uses the matter carried as the tool with which the deepening is done and with no waste at all a stream would be all but powerless to abrade its bed.

one is naturally rather hesitant about accepting *à priori* arguments unsubstantiated by other data. It was, therefore, highly desirable to submit this conclusion to experiment and to test its validity. Fortunately, as is well known, the dynamics of river action may be observed in any wayside streamlet after a rain. Accordingly, an effort was made to bring such a streamlet under experiment where the conditions could be controlled. The stream selected was one flowing down a steep grade, so that the current was quite swift. Before it was disturbed it was nearly straight, as such streams usually are. To expedite the experiment, it was turned from its course and made to follow a set of meanders constructed for it. In these prepared meanders each was approximately a semi-circle, and all were of about the same radius, so that the stream, except for accidental variation, due to differences in the number of larger pebbles in its bed, had nearly uniform conditions throughout the portion under experiment. To keep accurate record of the initial position, small sticks were driven into the banks in pairs, one on each side of the current. From a point near the middle of the set of meanders, sand was dumped into the current as fast as it could carry it away, so that one half of the course was heavily loaded, the other lightly. The amount of sand supplied was so great that it could be carried but a few inches before it was dropped, forming miniature sand-bars. These were built out from the lower side of each meander, so as to move the projecting point of the convex bank down stream. This narrowed the channel and forced the water against the opposite bank, which began to crumble and wear away. After about fifteen minutes of this treatment the meanders were appreciably more crooked. In some cases the change was so considerable that all of the swift portion of the current had moved over outside that of the peg originally set at its convex edge, which now stood, therefore, at the concave edge. But in the upper half of the course laid out no change was apparent in the same time. To check the result further the upper half of the course was then overloaded as had been the lower. The response was immediate and identical to that of the lower half. This would seem to show beyond a doubt that a swift stream can be made to meander simply by giving it a heavy load to carry.

But a stream can never build up a bar above its own level, or even quite up to that level, so that in the experiment, though the whole current was deflected against the farther bank as described, there was always a slight amount of water covering the top of the bar. In the streamlets experimented with, which were of nearly constant

volume, a point was reached if the experiment was carried far enough, where the retardation of the current, by its increasingly crooked course and the slight difference in level between the upper and lower sides of the bar built out, gave sufficient head to the shallow water moving across it to enable it to pick up the recently-deposited sand and cut a new channel through it before the meander had been worked out to nearly so great a departure from the original course as is usual in a large river. The cause of the difference is easy to see. In the river the bars are built up above the normal level at every slight rise, thus cutting off the flow across the meander before there is danger of the head across it equalling the force which deflects the water into the longer course. Thus we see that, for the maintenance of a meandering course, variations in the level of a stream are of considerable importance. It is a matter of common experience that meandering streams are usually subject to variations in volume from time to time. The growth of plants is very important in this connection; for in the river the bars are almost at once occupied by plants which by their roots compact and bind together the loose material and by their tops catch more at the next rise, so at once helping to hold the material already deposited and to catch more.

Besides these experiments observations were made upon streamlets lightly loaded with detritus. In such streams, though the force of the current was probably strongest on the outside banks of the bends as assumed in the common explanation of meanders given above, there was still some force left to abrade the inside bank, causing a wearing away of the projecting point on the inside, which, if continued, soon furnishes the stream with a shorter course at a higher grade. This new channel diverts more and more of the current, so that in a little while the stream has abandoned its meander and is following the straighter course. Thus a stream is enabled to straighten its course if it be not so heavily loaded that it must deposit débris with small checks to the current. And we begin to see how it is that swift streams, being usually lightly laden, are "less easily turned aside and maintain straighter courses" than those which, by reason of their smaller velocities and soft valley bottoms, are apt to be heavily loaded. As noted above, the Buffalo, in portions of its lower course, is cutting both of its banks; and while the cut on the inside bank seems not to be sufficient in this case to result in straightening the stream, it certainly must retard its lateral wandering and tend to keep it in its bed.

Deposition on the slackwater sides of obstructions in the current

of a river assumes, then, a very considerable importance. Its function is threefold: (1) As shown above, it is a controlling factor in the downward-cutting power of a stream; (2) by building out bars behind obstructions it prevents the stream from removing the obstructions and straightening its course; (3) these bars narrow the channel and force the water yet more strongly against the opposite concave bank, causing it to be worn away more rapidly.

Returning to the Buffalo River, we are in a better position to understand the anomaly it presents of a swift stream rapidly meandering. As described above, its banks are composed exclusively of sand and gravel, so loosely compacted that they offer even less resistance to the wearing of the water than the alluvium of most flood-plains, and as soon as it is touched by a current of the requisite velocity it is whirled away. The stream is thus enabled to pick up on the outside of every bend almost as much as it can carry. A part of this load it is compelled to drop only a few rods below in the slackwater at the next convex bank. The nature of the material is especially favourable to sudden deposition; for the sand and pebbles which make its bank are so coarse that they settle rapidly, affording strong contrast in this respect to fine silt, which requires some minutes to settle even in perfectly still water. The importance of this is manifest, if it be remembered that the slackwater spaces of a small stream are very short, so that such fine silt, even though it might have time to settle in the mile-long slacks of a great Mississippi, would in the Buffalo, before it had reached the bottom, have moved into another riffle, and so its final deposition would be rendered very uncertain. Thus we understand how our stream goes on continually eating out its meanders and building up its flood-plain at a rate incredible to a student familiar only with such sluggish meandering rivers as the Mississippi.

Summarising our results, we may state—partially, at least—the factors controlling the meandering of streams. Meandering is independent of velocity. It is possible only when the stream is so heavily loaded with waste that it begins to precipitate its load with comparatively slight checks to its velocity. A stream, to meander, must be subject to variations in volume. The direct causes of meandering are two: First, the tendency of a loaded stream to deposit sediment behind any obstacle projecting into the current. Such deposits have a double effect: They protect the obstruction from wear and prevent the stream from gradually removing it and straightening its course; and they aid the obstruction in deflecting the current against the opposite bank. The second cause of meandering is the lateral cutting of a current of water, flowing in a crooked channel, on the

outside of the bends which confine its course. This is brought about by the centrifugal force of the moving water. These two causes are complementary; each aiding the other, and together giving rise to the remarkable shifting in the channels of such streams as the Buffalo River.

THE BRITISH NATIONAL ANTARCTIC EXPEDITION.

BY

PROF. ANGELO HEILPRIN.

The narrative of the British National Antarctic Expedition of 1901–4, which has latterly been given to the world in two sumptuous volumes entitled "The Voyage of the Discovery,"* establishes for that expedition a just claim to being considered one of the most successful of all Polar ventures. No earlier voyage of discovery into the icy seas, whether in the north or in the south, has more distinctively accomplished its mission than this one; and none has treated more attractively and satisfyingly of the deeds of its explorers, or given in more graphic form the picture of a long-protracted struggle with nature and of the courage and self-denial which sustained this struggle.

Captain Robert Falcon Scott, R. N., the commander of the expedition, has easily earned the distinctions which have been conferred upon him, for he has not only established a far-reaching Antarctic record in his penetration (on Dec. 30, 1902) to lat. 82° 17' S.—an advance of nearly 250 miles on his predecessors—but in minor explorations he did much that, wholly apart from the major explorations, would have given a more than reputable standing to the ordinary aspirant for fame. Of such explorations may be cited the survey of the great Ross Barrier to the point of its disappearance in the easterly King Edward VII. Land and the traverse of the lofty snow and ice plateau which, in South Victoria, extends westward from the Admiralty and Prince Albert Mountains, and rises in its bleak and desolate form, the counterpart of the great ice-cap of Greenland, to elevations of 8,000–9,000 feet or more.

Naturally, the chief interest in the narrative centres about the long southern journey and the traverse of the great Antarctic Barrier which bounds the Ross Sea on the south in about lat. 78° S., and so effectually barred the progress of James Clark Ross sixty years earlier. This vast mass of ice, which extends in an

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* Charles Scribner's Sons, 1905.